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McPherson et al.

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(54) **LOW PROFILE, HIGHLY CONFIGURABLE, CURRENT SHARING PARALLELED WIDE BAND GAP POWER DEVICE POWER MODULE**

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Related U.S. Application Data

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H05K 1/02 (2006.01)
H01L 23/373 (2006.01)
H01L 25/07 (2006.01)
H01L 23/049 (2006.01)
H01L 23/15 (2006.01)
H01L 23/498 (2006.01)

(52) **U.S. Cl.**
CPC **H05K 1/0296** (2013.01); **H01L 23/049** (2013.01); **H01L 23/3735** (2013.01); **H01L 25/07** (2013.01); **H01L 23/15** (2013.01); **H01L 23/49861** (2013.01)

(58) **Field of Classification Search**
USPC 361/760, 747; 174/260
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

6,307,755	B1	10/2001	Williams et al.	
7,687,903	B2	3/2010	Son et al.	
7,786,486	B2	8/2010	Casey et al.	
8,018,056	B2	9/2011	Hauenstein	
8,368,210	B2	2/2013	Hauenstein	
2006/0133055	A1*	6/2006	Uematsu	H01L 23/50 361/760
2013/0010446	A1*	1/2013	Henrik	H01L 21/56 361/783

OTHER PUBLICATIONS

R.K. Ulrich and W.D. Brown, "Advanced Electronic Packaging," New Jersey: John Wiley & Sons, Inc., 2006, p. 203.
Shengnan Li, "Packaging Design of IGBT Power Module Using Novel Switching Cells," Ph.D. dissertation, University of Tennessee, 2011.

* cited by examiner

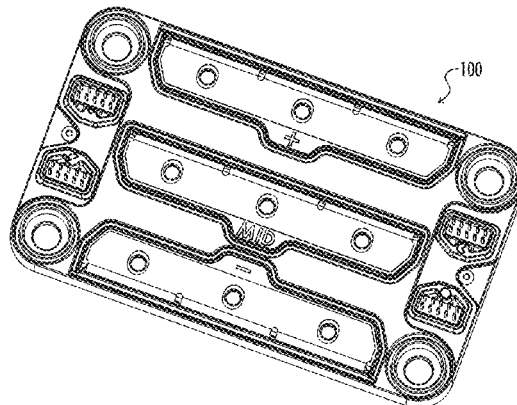
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(57) **ABSTRACT**

A power module with multiple equalized parallel power paths supporting multiple parallel bare die power devices constructed with low inductance equalized current paths for even current sharing and clean switching events. Wide low profile power contacts provide low inductance, short current paths, and large conductor cross section area provides for massive current carrying. An internal gate & source kelvin interconnection substrate is provided with individual ballast resistors and simple bolted construction. Gate drive connectors are provided on either left or right side of the module. The module is configurable as half bridge, full bridge, common source, and common drain topologies.

18 Claims, 19 Drawing Sheets



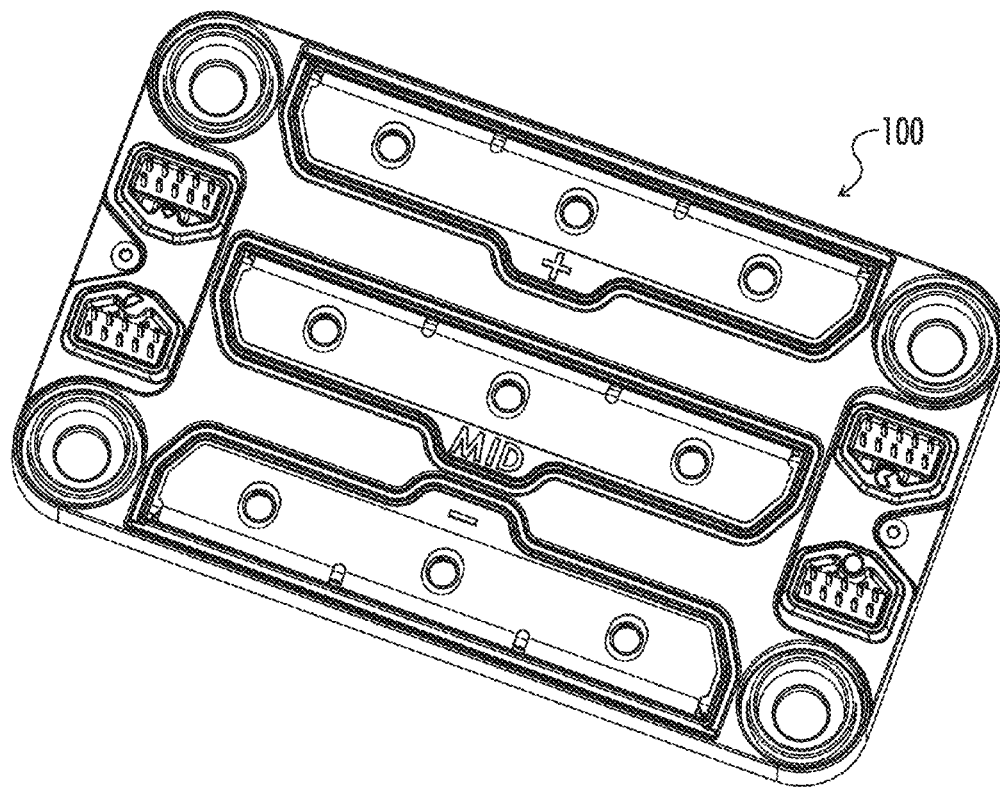


FIG. 1

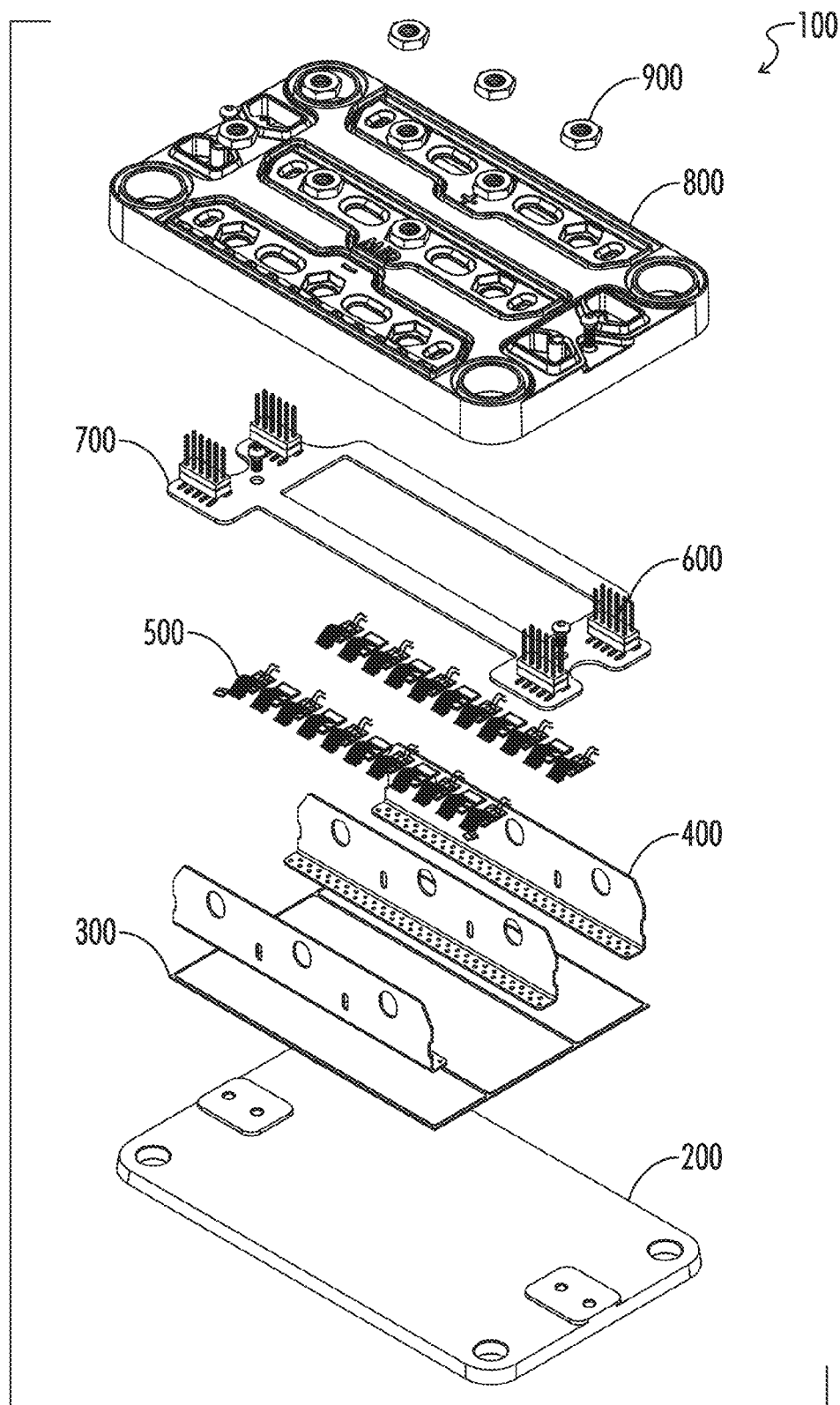


FIG. 2

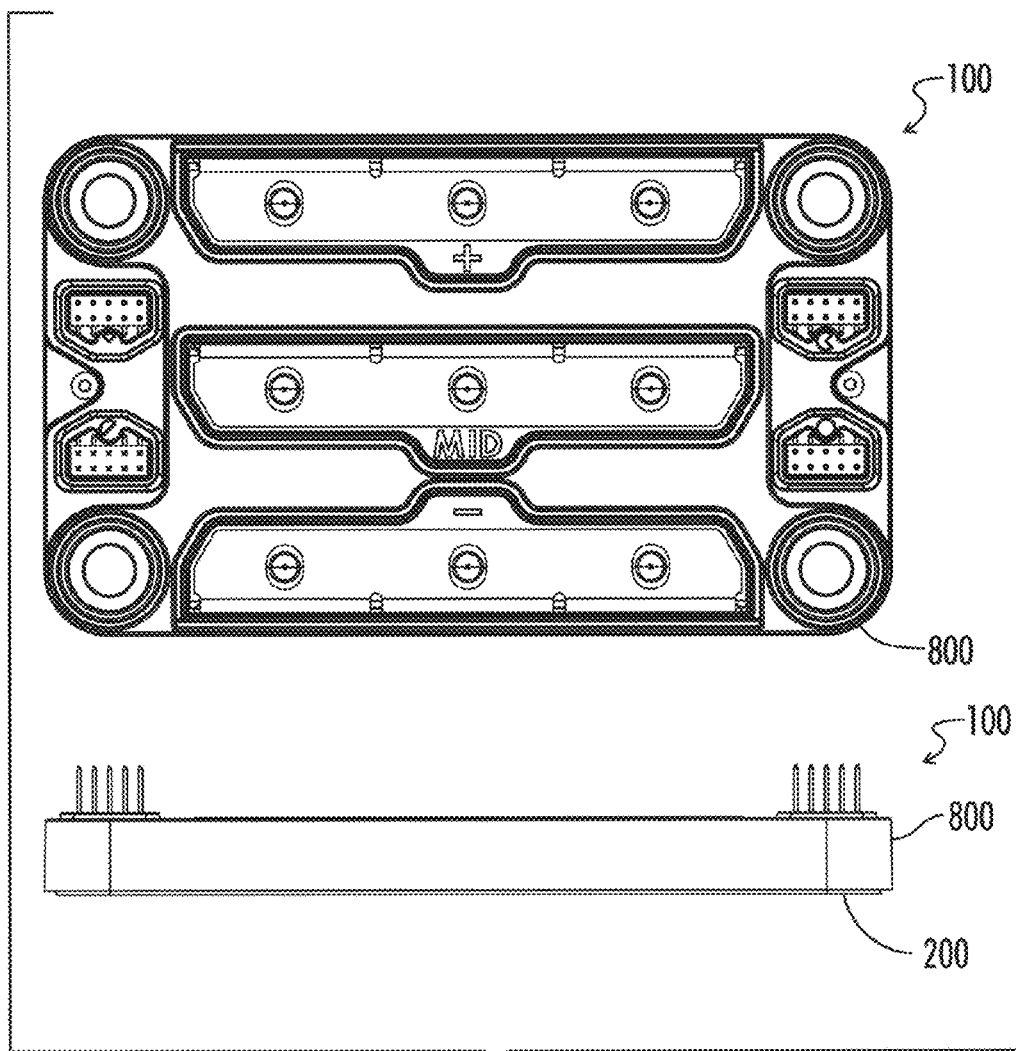


FIG. 3

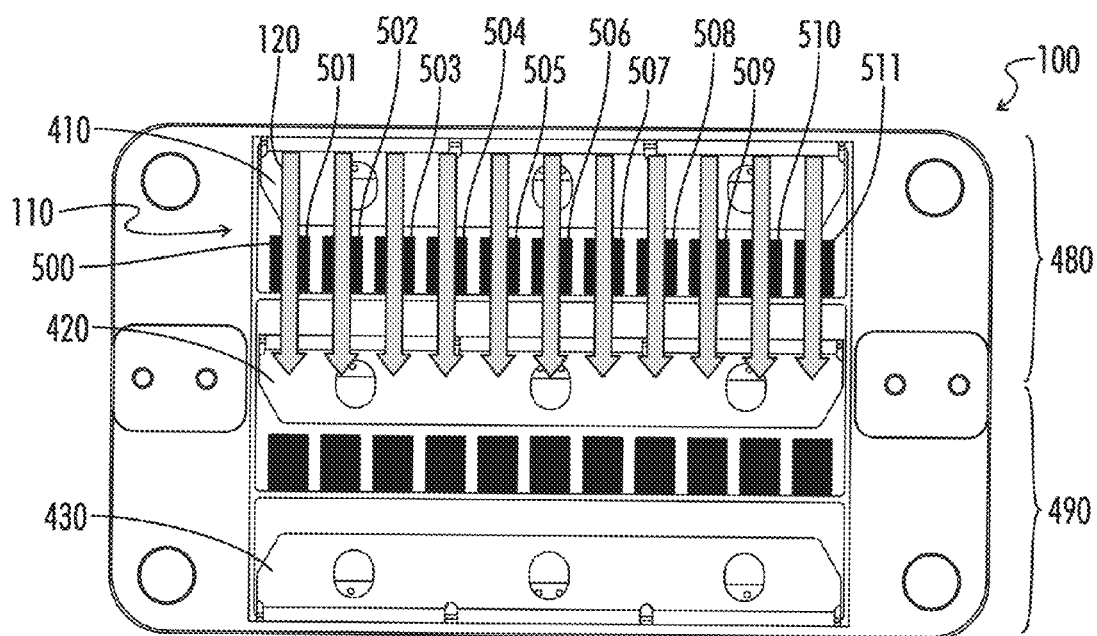


FIG. 4

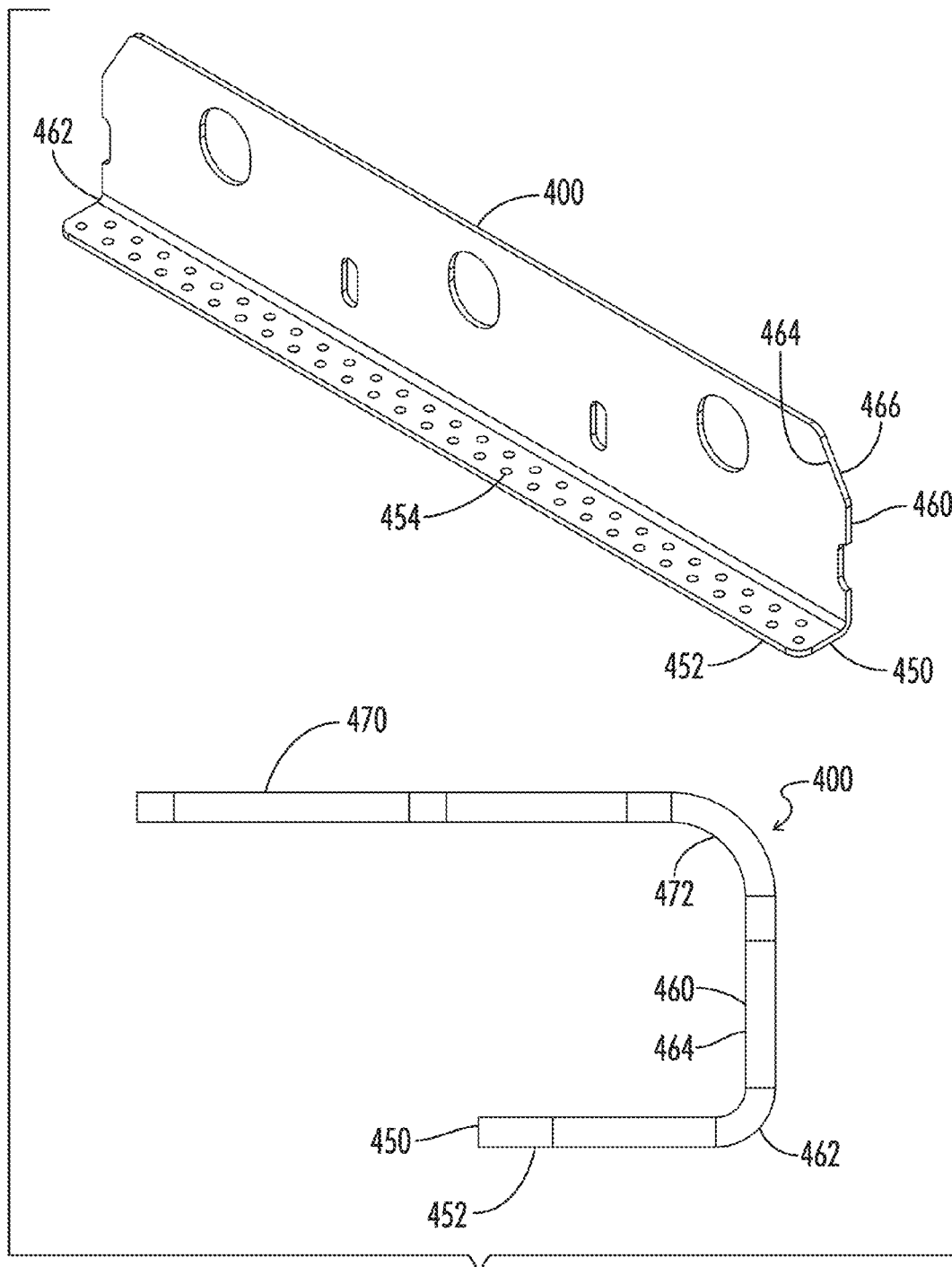


FIG. 5

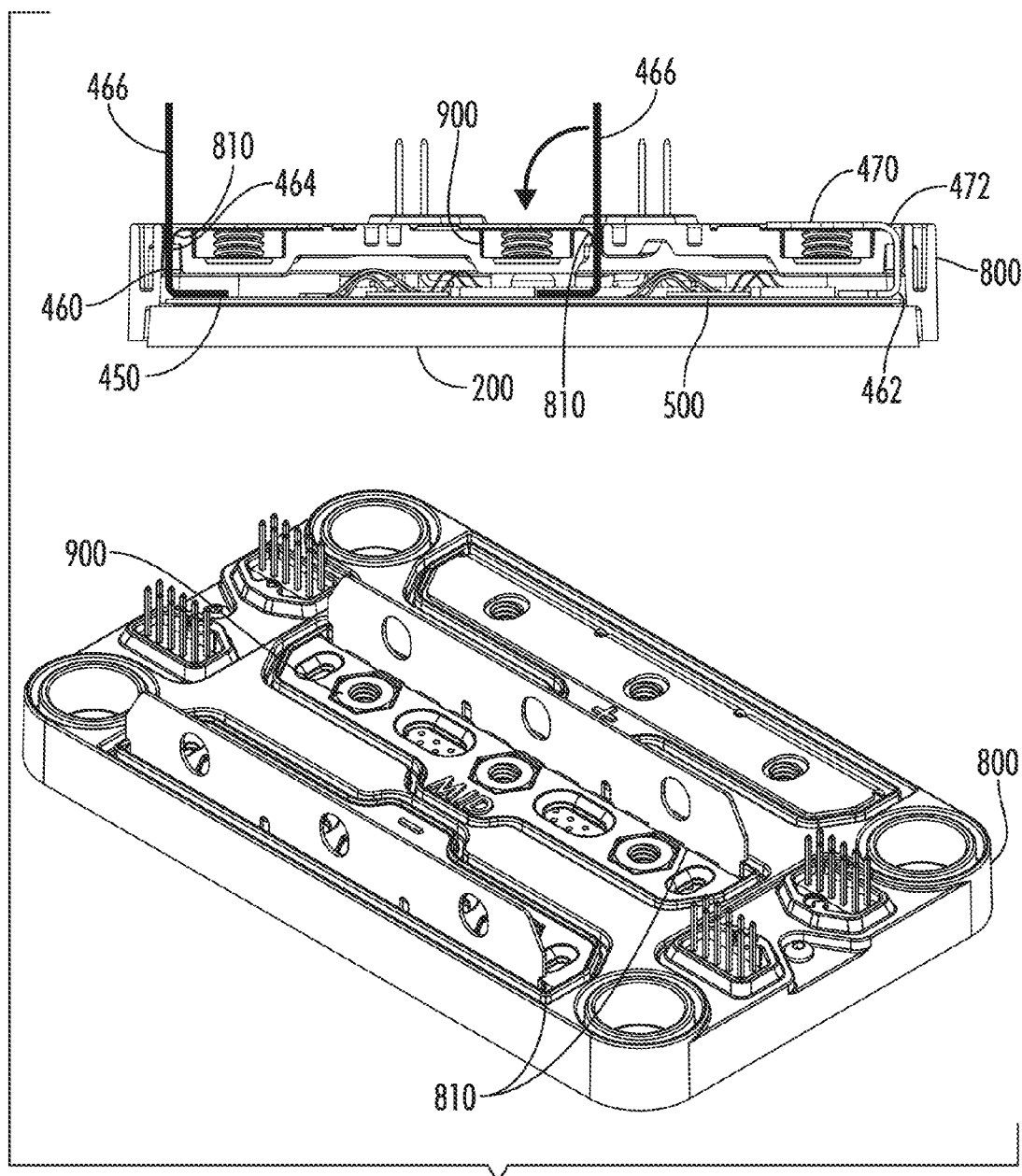
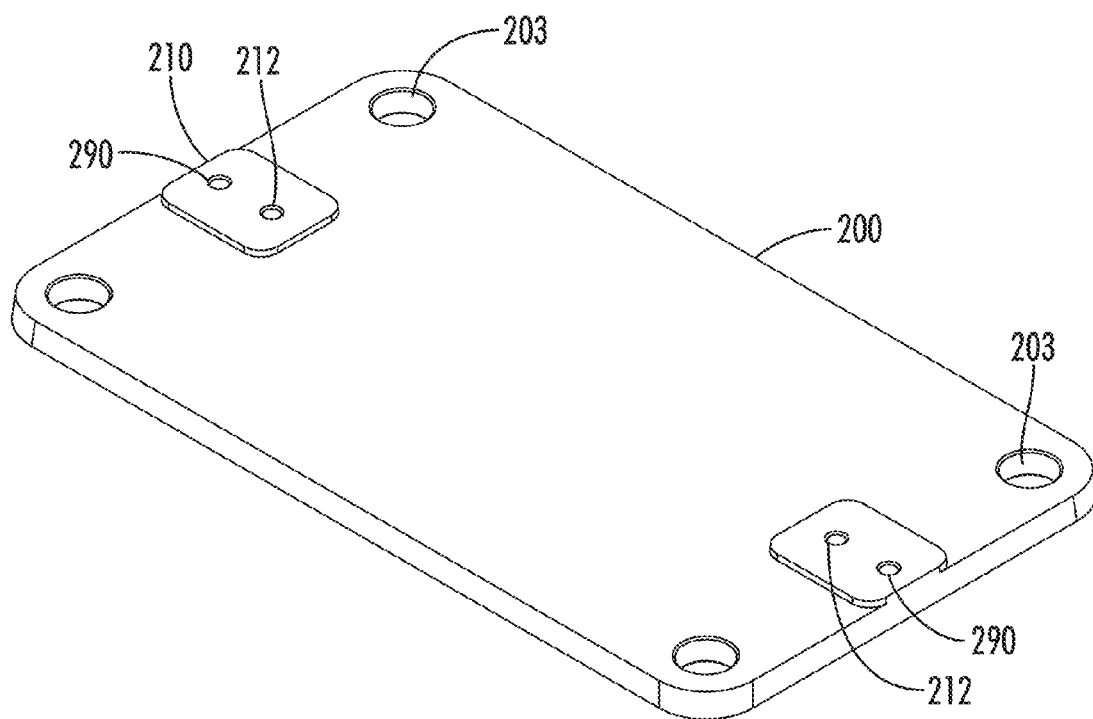


FIG. 6

*FIG. 7*

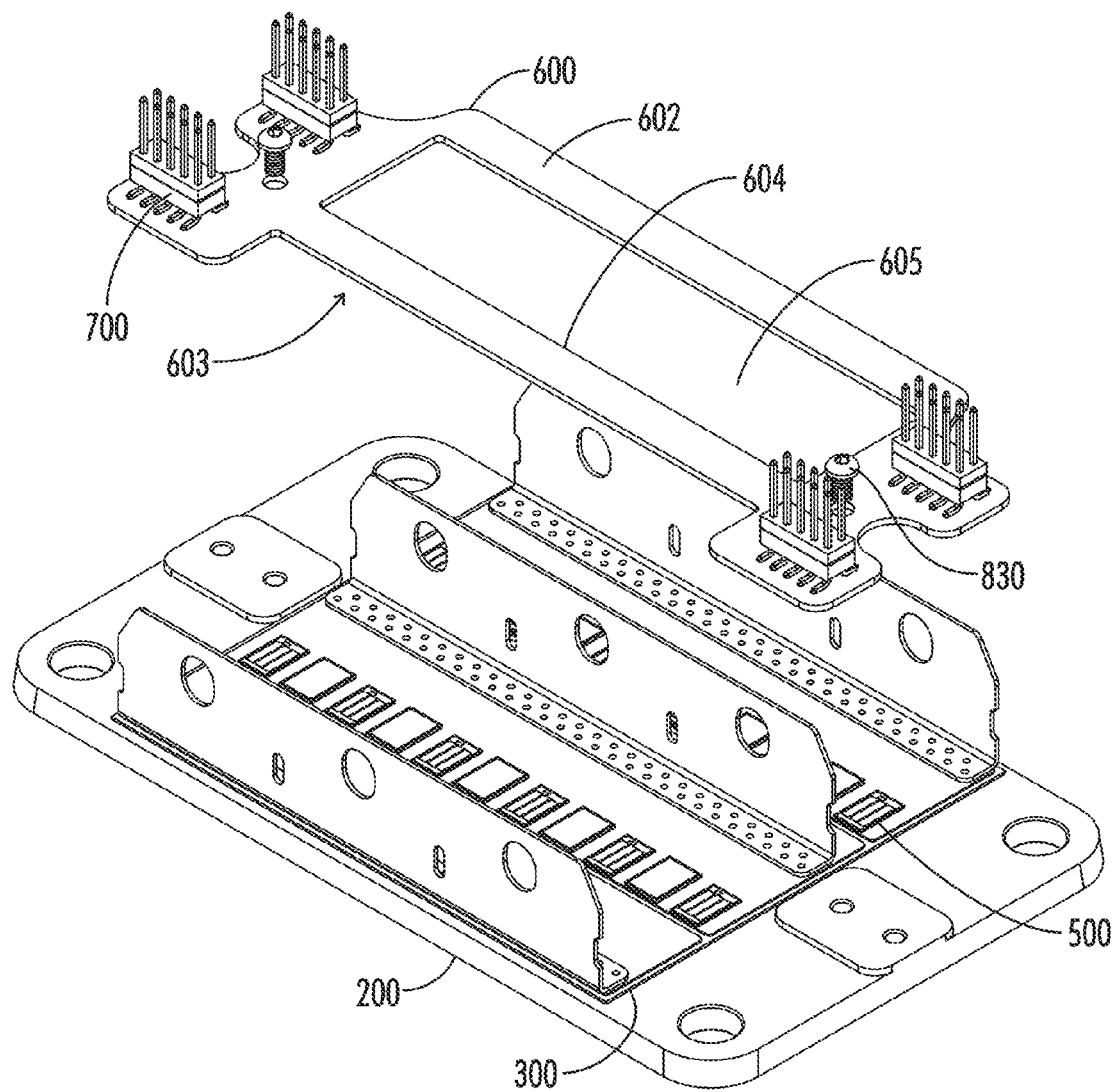


FIG. 8

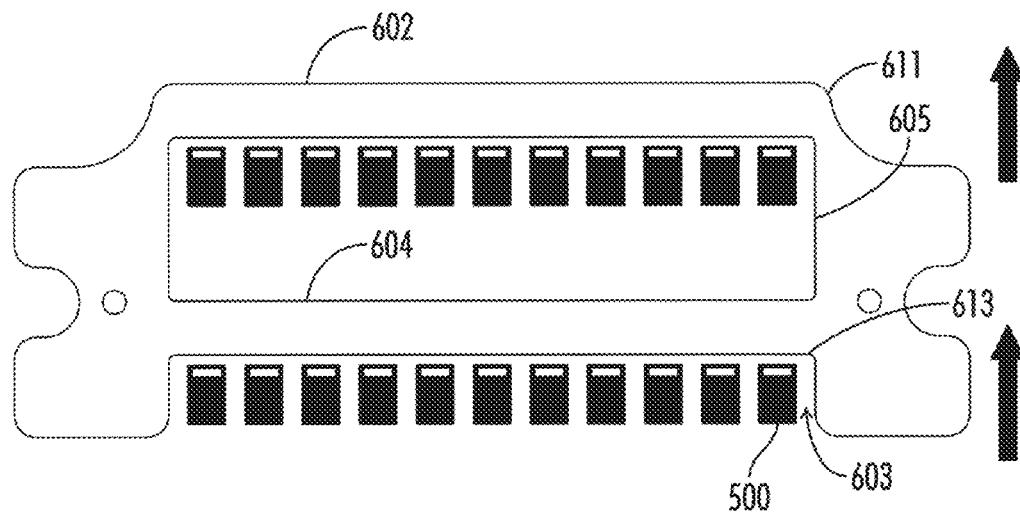


FIG. 9

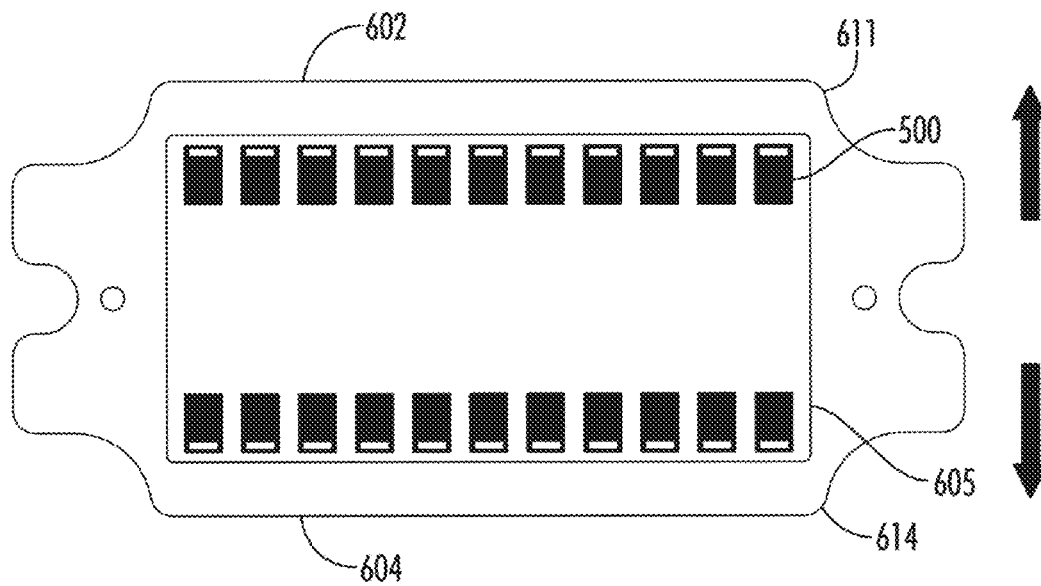


FIG. 10

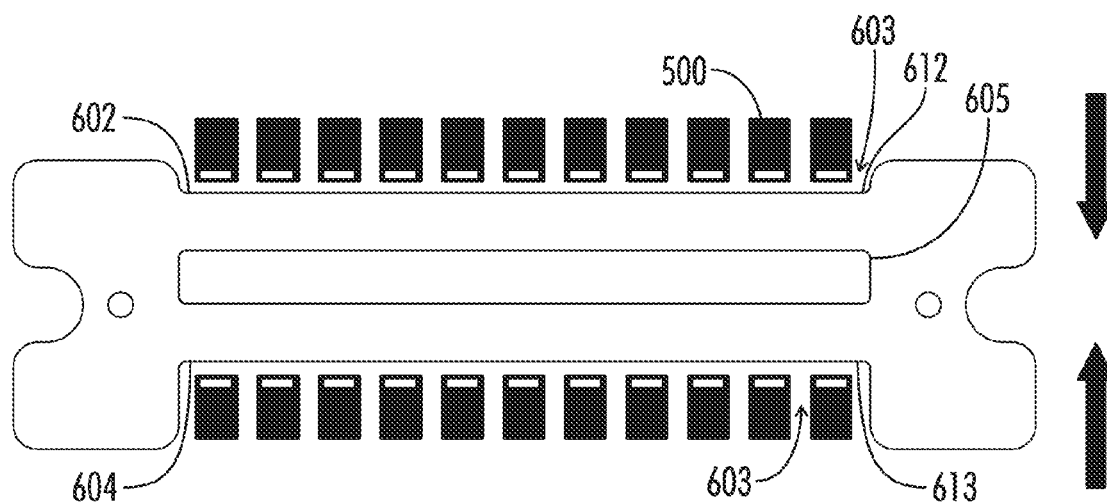


FIG. 11

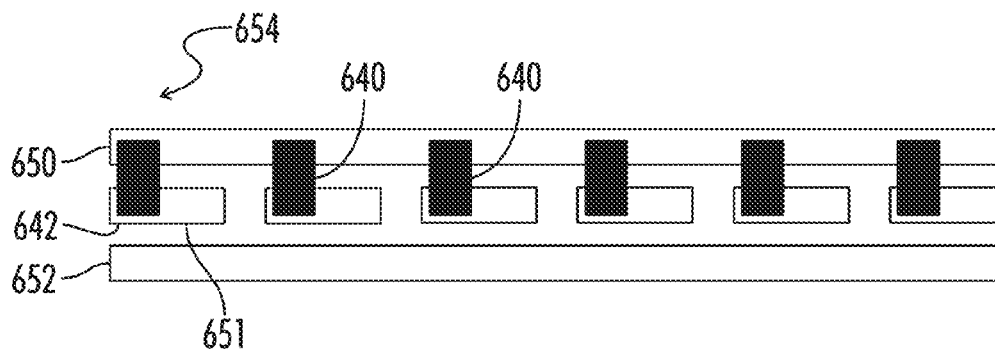


FIG. 12

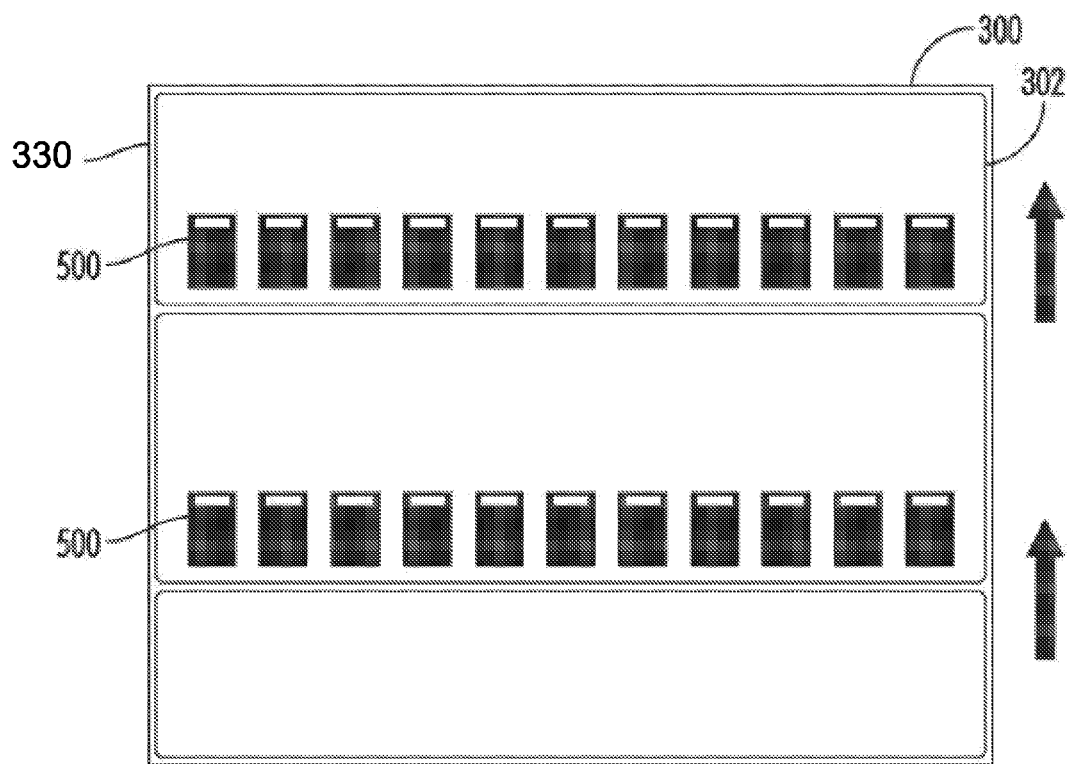


FIG. 13

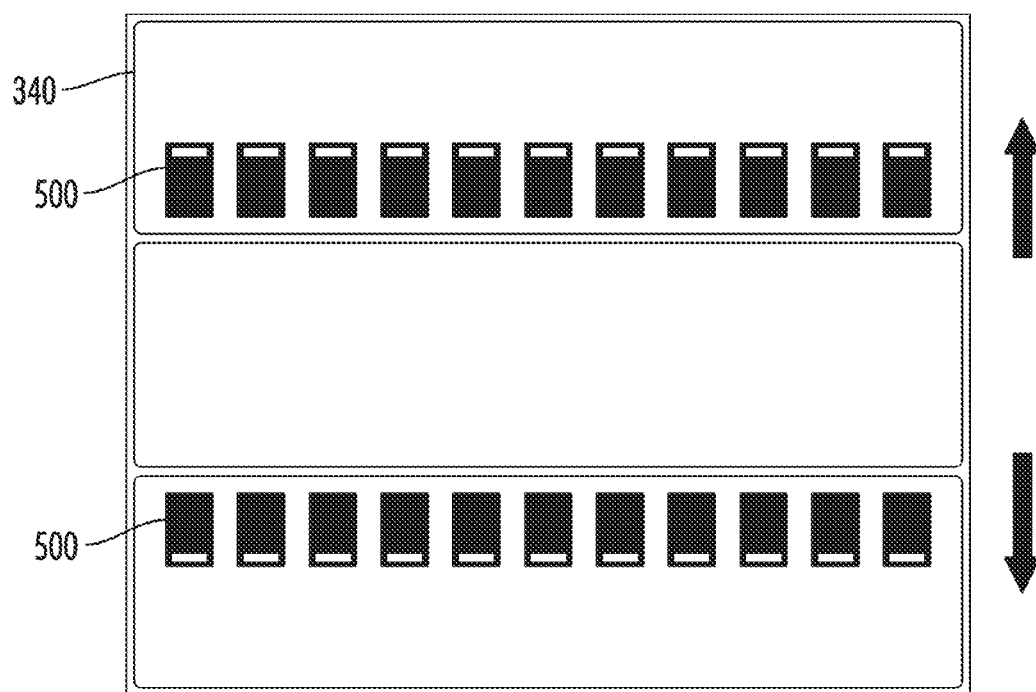


FIG. 14

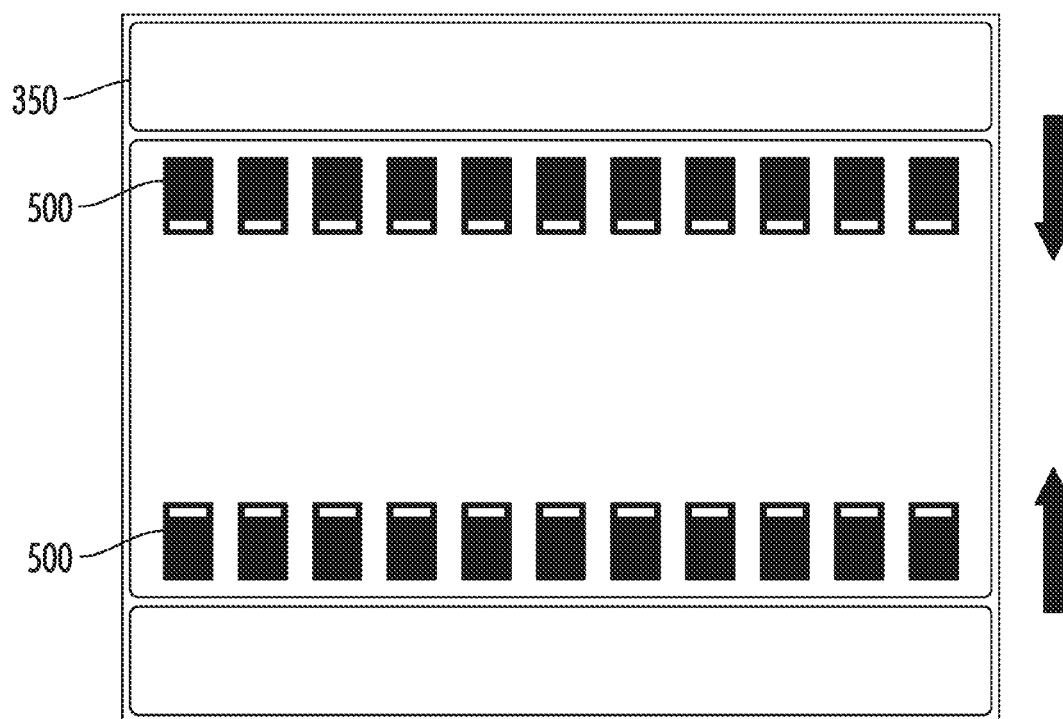
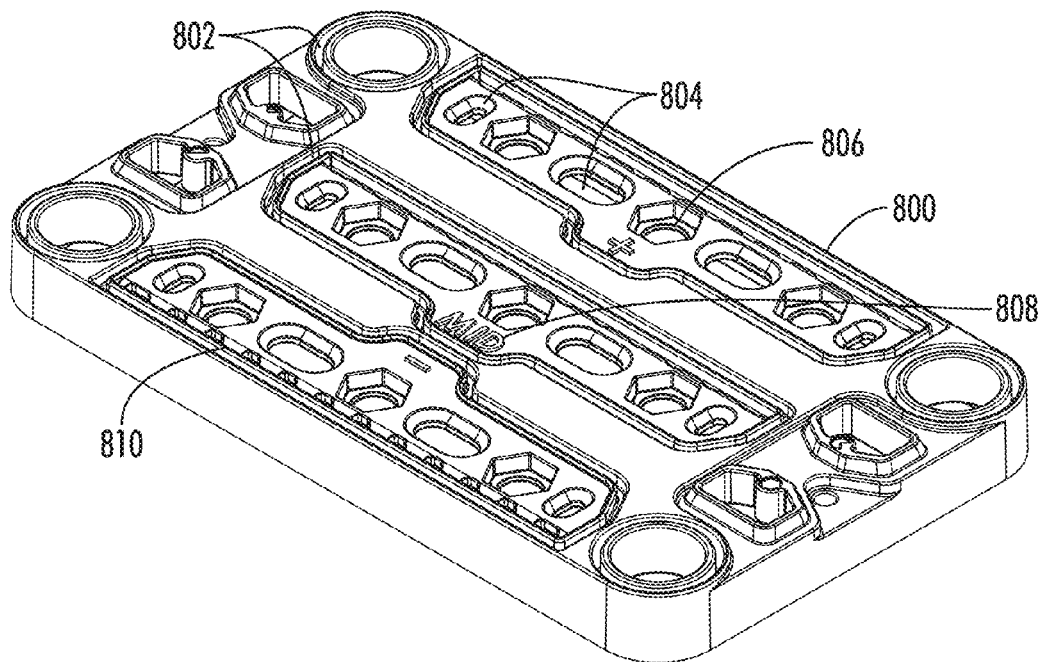


FIG. 15

*FIG. 16*

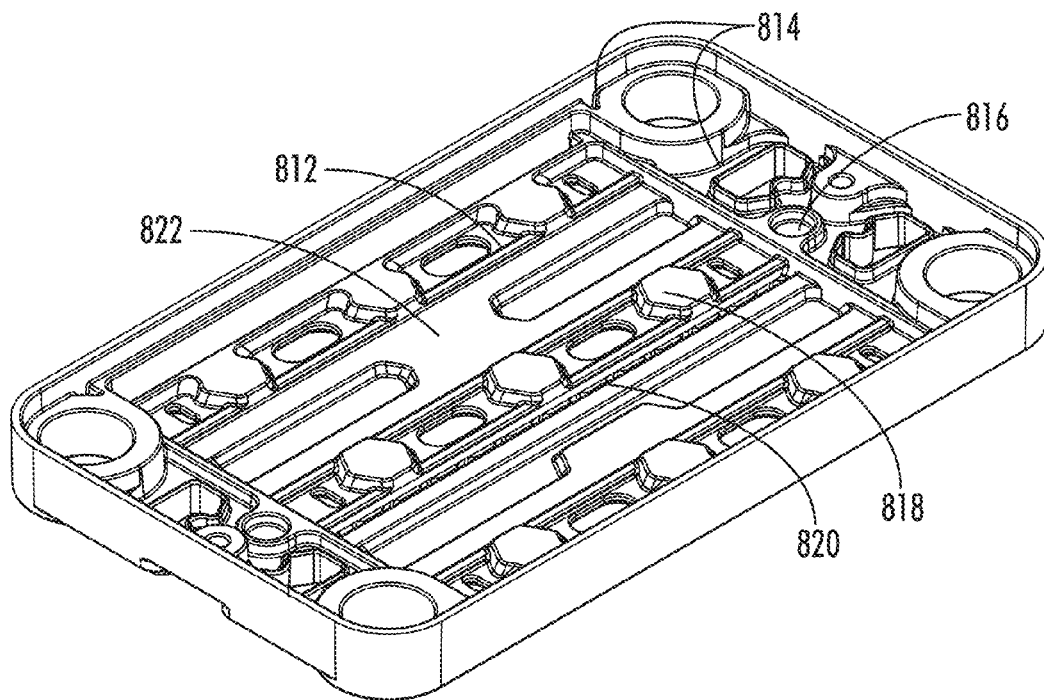


FIG. 17

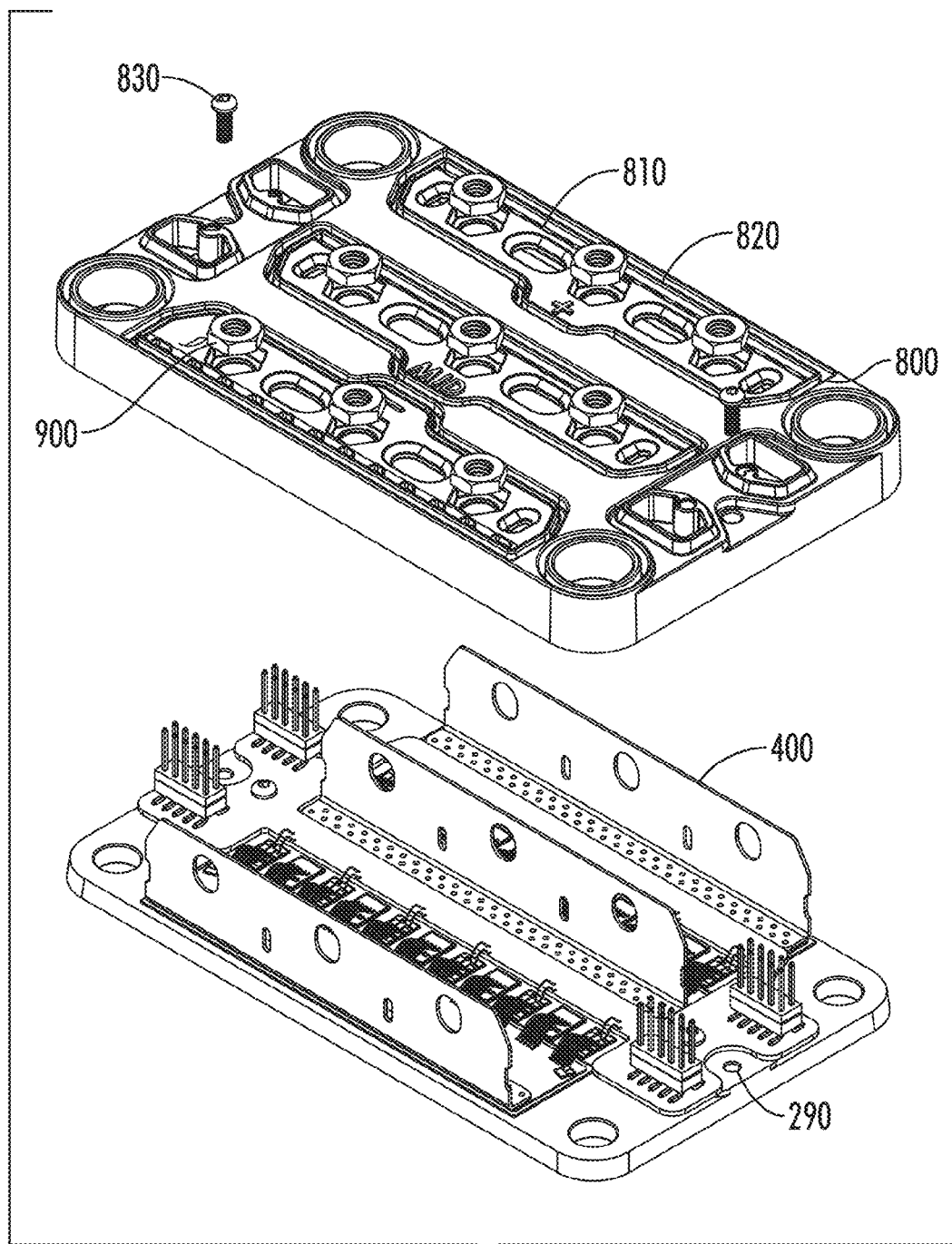


FIG. 18

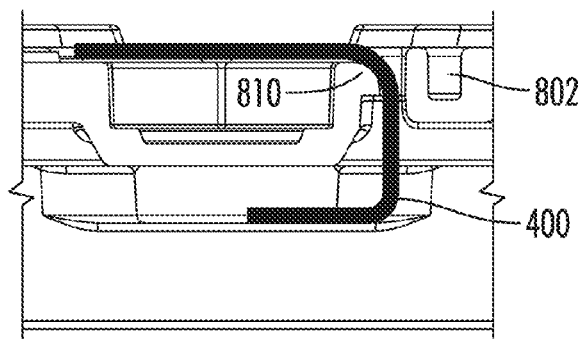


FIG. 19

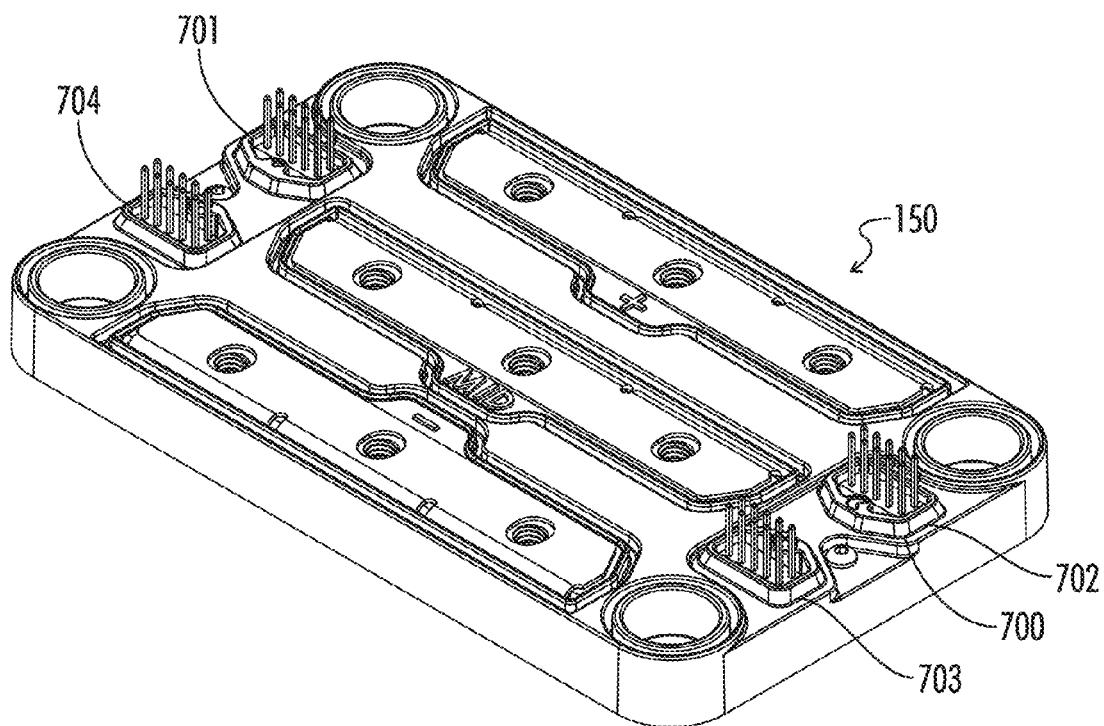


FIG. 20

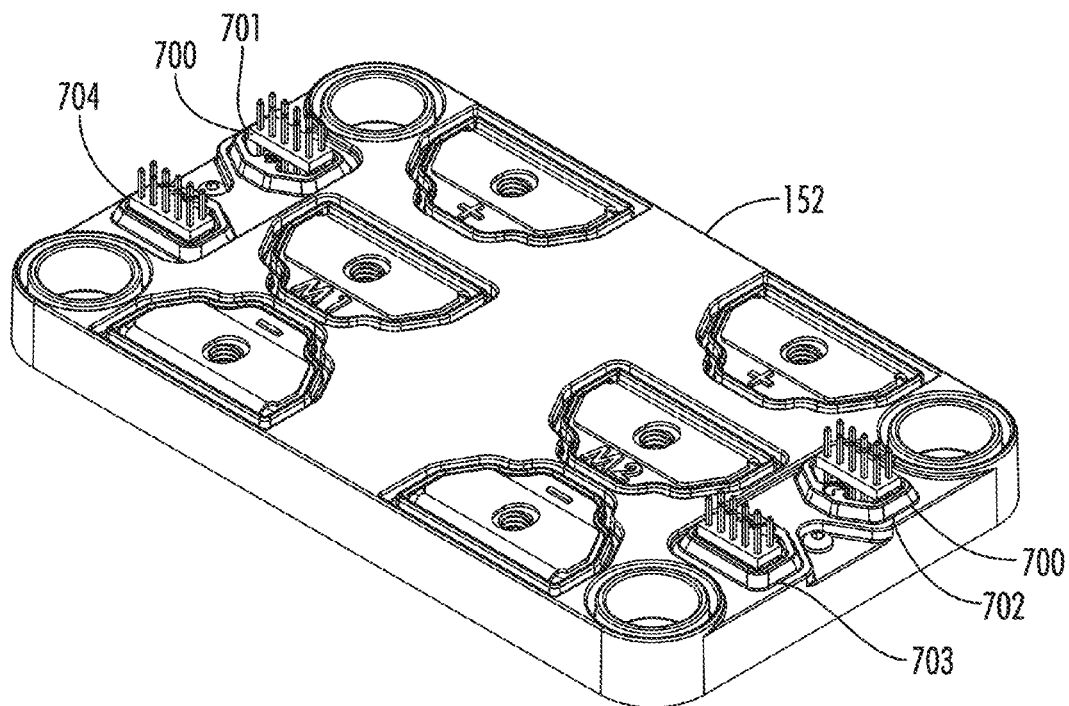


FIG. 21

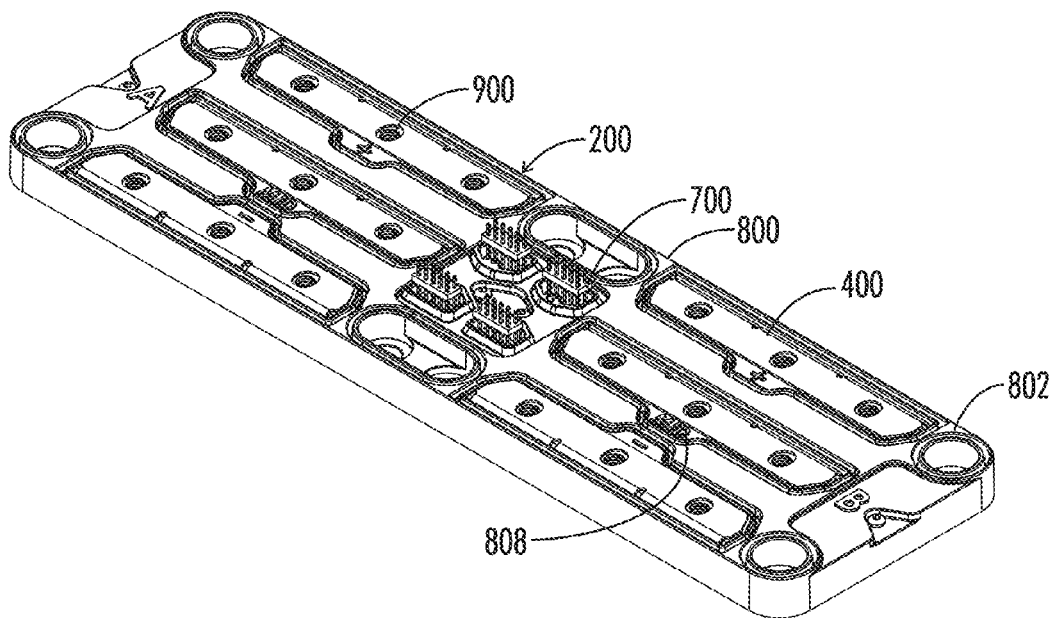


FIG. 22

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**LOW PROFILE, HIGHLY CONFIGURABLE,
CURRENT SHARING PARALLELED WIDE
BAND GAP POWER DEVICE POWER
MODULE**

**CROSS-REFERENCE TO RELATED
APPLICATIONS**

This application claims priority to and is a continuation-in-part of U.S. Provisional Patent Application Ser. No. 61/933,535, filed on Jan. 30, 2014 entitled LOW PROFILE, HIGHLY CONFIGURABLE POWER MODULE FOR EQUAL CURRENT SHARING OF MANY PARALLELED WIDE BAND GAP POWER DEVICES which is hereby incorporated by reference in its entirety.

**STATEMENT REGARDING FEDERALLY
SPONSORED RESEARCH OR DEVELOPMENT**

This invention was made with government support under grant FA8650-10-C-2124 awarded by the United States Air Force and grant DE-EE0006429 awarded by the Department of Energy. The United States government has certain rights in the invention.

REFERENCE TO A MICROFICHE APPENDIX

Not Applicable.

RESERVATION OF RIGHTS

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BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to improvements in wide band gap power modules. More particularly, the invention relates to improvements particularly suited for providing a configurable consistent power module design for multiple applications. In particular, the present invention relates specifically to a parallel path power module allowing for current sharing at high switching frequencies.

2. Description of the Known Art

As will be appreciated by those skilled in the art, power modules are known in various forms. Patents with information of interest to power modules include: U.S. Pat. No. 7,687,903, issued to Son, et al. on Mar. 30, 2010 entitled Power module and method of fabricating the same; U.S. Pat. No. 7,786,486 issued to Casey, et al. on Aug. 31, 2010 entitled Double-sided package for power module; U.S. Pat. No. 8,018,056 issued to Hauenstein on Sep. 13, 2011 entitled Package for high power density devices; U.S. Pat. No. 8,368,210 issued to Hauenstein on Feb. 5, 2013 entitled Wafer scale package for high power devices; U.S. Pat. No. 6,307,755 issued to Williams, et al. on Oct. 23, 2001 entitled Surface mount semiconductor package, die-leadframe combination and leadframe therefore and method of mounting leadframes to surfaces of semiconductor die. Additional articles include: R. K. Ulrich and W. D. Brown, "Advanced Electronic Pack-

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aging," New Jersey: John Wiley & Sons, Inc., 2006, p. 203; and Shengnan Li, "Packaging Design of IGBT Power Module Using Novel Switching Cells," Ph.D. dissertation, University of Tennessee, 2011, http://trace.tennessee.edu/utk_graddiss/1205. Each of these patents and publications are hereby expressly incorporated by reference in their entirety.

Wide band gap power semiconductors, including Silicon Carbide, SiC, and Gallium Nitride, GaN, offer numerous advantages over conventional Silicon, Si, based power electronic devices, including:

1. Reduced intrinsic carriers allowing for higher temperature operation
2. Increased carrier mobility
3. Higher electrical breakdown strength
4. Reduced on-resistance
5. Faster switching speeds
6. Increased thermal conductivity

These benefits allow for designers to implement systems which are substantially smaller, more efficient, and more reliable than the current state-of-the-art systems. Higher temperature operation allows for the reduction of the cooling system required to remove waste heat. The potential also exists to switch from an active, i.e. forced air or liquid, cooling scheme to passive, natural convection, cooling, elimination of thermal shielding materials, and operation in extreme environments where traditional technology will fail. High frequency switching reduces switching losses and allows for a major reduction in the size of filtering elements in a power converter.

The promises of wide band gap power technology, however, are hindered by the power packaging necessarily to interconnect, protect, and integrate the devices into a power conversion system. Power packages for Si devices are generally designed to house one large device per switch position, often with a single antiparallel diode. Commercially available wide band gap devices, however, are not available as large, monolithic elements due to issues with wafer quality and yield. Accordingly, while the relative power density, per die area, for SiC is substantially higher than Si, in order to reach high currents, in the hundreds of amps, many SiC devices must be placed in parallel.

There is a fundamental issue with paralleling many devices in conventional packages which were not designed to effectively account for issues such as current sharing. This is particularly important due to the extremely high switching speeds of wide band gap devices, often hundreds of times faster than Si equivalents. Mismatches in inductances between the devices may cause uneven stresses and current overshoot during switching events. Additionally, the materials, attaches, and interfaces of established power module technology are not capable or reliable at the temperatures which wide band gap devices are operable.

From this, it may be seen that the prior art is very limited in its teaching and utilization, and an improved power module is needed to overcome these limitations.

SUMMARY OF THE INVENTION

The present invention is directed to an improved power module using parallel power devices. In accordance with one exemplary embodiment of the present invention, a power module is provided with low inductance equalized current paths to many paralleled devices, allowing for even current sharing and clean switching events. The power module is capable of running at junction temperatures ranging from 200 to 250° C., depending on devices, operating conditions, etc. and may carry very high currents, 100 s of amps and greater.

Chiefly, these enhancements fall into three categories: 1 performance, 2 function, and, 3 usability. This technology is designed from the ground up to embrace the characteristics and challenges of wide band gap power devices. Features of the power module include the following highlights:

Matched footprint with industry standard 62 mm base plates.

Equalized power paths for effective paralleling of bare die power devices.

Large active area available for devices, 7.5 mm×71 mm per switch position.

Low module height, 10 mm.

Low inductance achieved with wide, low profile power contacts.

Short current path and large conductor cross section area for massive current carrying, >500 A.

Internal gate & source kelvin interconnection substrate with individual ballast resistors.

High reliability bolted connection of the internal gate & source kelvin interconnection substrate.

Standardized, and configurable 1 mm, 2 mm, 0.1 in, and 0.05 in pitch gate drive connectors.

Gate drive connectors on either left or right size of the module.

Option for internal temperature sensing RTD and associated input/output connectors.

Reduced unique part count to reduce system cost.

Reduced unique part count to increase modularity.

Configurable as half bridge, full bridge, common source, and common drain topologies.

Voltage creepage extenders incorporated into the plastic housing.

Lightweight through the use of low density materials, ~140 g in total.

Materials, attaches, and voltage blocking passivation capable of operating up to 250° C.

These and other objects and advantages of the present invention, along with features of novelty appurtenant thereto, will appear or become apparent by reviewing the following detailed description of the invention.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWINGS

In the following drawings, which form a part of the specification and which are to be construed in conjunction therewith, and in which like reference numerals have been employed throughout wherever possible to indicate like parts in the various views:

FIG. 1 shows a perspective view of the power module.

FIG. 2 shows an exploded view of the power module.

FIG. 3 shows a relative size to thickness comparison of the power module.

FIG. 4 shows the equalized current flow for multiple paralleled devices.

FIG. 5 shows the power contact design.

FIG. 6 shows the low profile power contact bending.

FIG. 7 shows the power module base plate.

FIG. 8 shows the gate and source kelvin secondary substrate,

FIG. 9 shows the gate & source kelvin board half bridge arrangement.

FIG. 10 shows the gate & source kelvin board common source arrangement.

FIG. 11 shows the gate & source kelvin board common drain arrangement.

FIG. 12 shows the single layer modular gate and source kelvin example layout.

FIG. 13 shows the power substrate half bridge arrangement.

FIG. 14 shows the power substrate common source arrangement.

FIG. 15 shows the power substrate common drain arrangement.

FIG. 16 shows the high temperature plastic housing topside features.

FIG. 17 shows the high temperature plastic housing back-side features

FIG. 18 shows the housing attach to power module assembly.

FIG. 19 shows the power contact guides.

FIG. 20 shows the half bridge, single channel common source or drain module.

FIG. 21 shows the full bridge, dual channel common source or drain module.

FIG. 22 shows the extended single housing side-by-side module configuration.

DETAILED DESCRIPTION OF THE INVENTION

As shown in FIG. 1 of the drawings, one exemplary embodiment of the present invention is generally shown as a power module 100. The power module 100 is configurable in multiple useful power electronic topologies such as half bridge, full bridge, common source, and common drain and can be configured in up to two separate channels. It is uniquely suited to take advantage of all wide band gap technology has to offer, while being flexible enough to meet the demands of many customer systems through custom configurations.

The power module 100 consists of the primary elements outlined in FIG. 2. These include the base plate 200, power substrate 300, power contacts 400, power devices 500, gate & source kelvin interconnection board 600, gate drive connectors 700, injection molded housing 800, and fasteners 900.

Specific focus was placed on using a footprint common in the power electronics industry, a 62 mm×107 mm base plate 200 with M6 mounting holes 48 mm×93 mm apart. Using a common footprint allows for customers with existing systems to evaluate these high performance modules 100 without investing in a complete system redesign.

While the length and width of the module 100 fits industry standards, the height of the module is 2× to 3× thinner than contemporaries. It is 10 mm thick in total. This dramatically reduces the module inductance and increases current carrying capability partially by utilizing lower path lengths. It may also provide a major source of system level volume savings in a power converter.

The comparison of top size to thickness dimensions of the power module 100 are presented in FIG. 3 in the top and side view comparison. The module 100 measures 65 mm×110 mm×10 mm. The plastic housing 800 extends like a sheath over the base plate 200 for voltage isolation, which accounts for the extra 3 mm on each side over the base plate 200 dimensions. It has a volume of 71.5 cm³ and weighs approximately 140 g.

The power module 100 utilizes 57.5 mm×73 mm, 42 cm², of the total footprint area for conduction. This is an impressive 60% utilization solely for current carrying. The remaining area is used for mounting, 5%, gate drive connections, 5%, and plastic features including minimum wall thickness, voltage creepage extenders, and strengthening ribs, 30%.

Power Loop

As noted by FIG. 4, the driving focus of the power module 100 power loop 110 is effectively paralleling large numbers of devices 500. Shown are a first power device 501, second power device 502, third power device 503, fourth power device 504, fifth power device 505, sixth power device 506, seventh power device 507, eighth power device 508, ninth power device 509, tenth power device 510, and eleventh power device 511. The module 100 can either have two or four switch positions, depending on configuration, which is detailed later. FIG. 4 shows the upper position 480 and the lower position 490. There is a large amount of flexibility in the formation of each switch position, such that they are tailored to specific applications without costly module 100 modifications. For example, the positions may have an equal number of diodes to the power switches 500, only a few diodes, or none at all. FIG. 4 is a representation of the power loop 110, depicting the even, shared current paths 120 for current traveling from the “V+” terminal 410 to the “Mid” terminal 420, the V-terminal 430 is also shown that is used for devices 500 in the lower position 490. An additional benefit of this layout is that the even spacing of each device 500 aids in the spreading of the heat sources across the module 100 instead of concentrating them in a few locations.

As displayed in FIG. 4, nearly the entire width of the power module 100 is utilized for the conduction of current. Many benefits would be lost if the module 100 was tall. In the worst case, the length the current would travel through the power contact 410, 420, 430 would be longer than the path it travels once it reaches the substrates 300. Accordingly, the power contacts 400 were designed to have a low height such that they contribute a negligible amount to the resistance and inductance of the system.

The low height of the power contacts 400 was achieved by using a dual bending process. First, the power contacts 400 are formed through either a metal stamping operation or by etching followed by forming in a press brake. The 90° bend at the base 450 creates an “L” shaped connector with a vertical body 460. The base 450 is soldered down to the power substrates 300. The base 450 is relatively thin in comparison to the overall shape. This reduces the area consumed by this bond, allowing for more active device 500 area inside of the module 100. To improve adhesion of this thin bond, staggered holes, called solder catches 454 are etched or formed along the bonding surface 452 on the bottom of the base 450. Molten solder travels up the catches 454 through capillary action. Once solidified, the solder inside of the catches 454 substantially improves bond strength in many directions. An exemplary contact 400 with solder catches 454 is presented in FIG. 5.

Also shown in FIG. 5 is how the “L” shaped contacts 400 are bent a second time at the end of the fabrication process to form a contact top 470. Before bending, the vertical body 460 of the contact 400 allows for a single piece plastic housing 800 to be dropped into place, as there are no undercuts present. The radius of the second bend 472 is not as tight as the first bend 462. This provides some tolerance in the process and is a smoother bending operation. The second radius 472 is facilitated through a pre-formed radius 810 in the plastic housing 800, which, at this stage, is touching the leading edge 464 of the contacts 400. Specifically designed rotating bending hardware presses flatly on the opposite surface 466, folding the contacts 400 down over the captive fasteners 900. An illustration of the bending of the “L” shaped contacts into “C” shaped forms is pictured in FIG. 6.

Underneath the folded contacts 400 are low profile threaded fasteners 900 shown as nuts 900. These fasteners

900 are captured underneath the power contacts 400. They are otherwise loose. The captive fasteners 900 serve an important purpose. When the module 100 is bolted to buss bars, the loose fasteners 900 and the contacts 400 are pulled upwards into the bussing, creating a quality electrical connection. If the fasteners 900 were affixed to the housing 800, they would act to pull the bussing down into the module 100 and could create a poor connection due to the stiffness of the buss bars.

Base Plate

The base plate 200 is a critical element of the module, providing mechanical support, heat spreading, and a means to effectively bolt down to a heat sink or cold plate. The material properties of the base plate 200 become increasingly important as the temperature of operation elevates. An effective example is found in the coefficient of thermal expansion, CTE, where materials in the assembly expand at different rates due to heat and may create large stresses in their interfaces.

The power module 100 utilizes a Metal Matrix Composite, MMC, material, which is a composite of a high conductivity metal, copper, aluminum, etc., and either a low CTE metal such as moly, beryllium, tungsten, or a nonmetal such as silicon carbide, beryllium oxide, graphite. These composite materials combine the best features of each contributing element, allowing for a high thermal conductivity with a CTE which is matched with the power substrate 300 to which it is attached.

FIG. 7 shows how the power module 100 base plate 200 was designed to match an industry standard 62 mm geometry, which has a set diameter and location for the mounting holes 203 in the corners. The thickness of the plate 200 was fine-tuned through the use of parametric finite element analysis of the CAD model. This was achieved by sweeping the thickness between pre-defined practical limits and measuring the thermal and mechanical responses. The material and thickness combinations that achieved the best thermal performance with a minimal mechanical deflection were selected. Additional features of the power module 100 plate include machined or molded, depending on the MMC material, standoffs 210 with a threaded board hole 212, and housing hole 290 each. The standoff 210 provides a planar surface with the power substrate 300 such that the internal gate & source kelvin board 600 can be bolted down without bowing.

Gate Drive Loop

Independent electrical paths for each switch position are required to form gate and source kelvin connections, which are necessary for controlling the power switches. This becomes difficult with the number of devices 500 in parallel, as ideally the gate and source kelvin routing would not interfere with the wide, equalized power paths. FIG. 8 shows how the power module 100 and its variations include a single piece secondary substrate 600 which is placed over the power substrate 300 and then bolted down to the base plate 200.

As shown in FIG. 8 through 11, the gate & source kelvin substrate 600 has two interconnection channels 602, 604 which may be located in one of four positions top or first 611, upper middle or second 612, lower middle or third 613, and bottom or fourth 614 to define die apertures such as an external die aperture 603 or middle die aperture 605 to allow for a multitude of module 100 configurations. Essentially, the relative layout of each interconnection channel 602, 604 is the same; however, the location and direction are adapted to match the associated die aperture 603, 605 and die 500 placement and rotation to match each topology. This is illustrated in FIG. 9, FIG. 10, and FIG. 11 with the arrows indicating the gate direction for a half bridge, common source, and common drain topology, respectively. Each of these may consist of a

single or dual channel arrangement, depending on the layout of the power substrate **300** and the format of the power contacts **400** and housing **800**.

As shown in FIG. 12, to aid in paralleling, individual ballast resistors **640** may be included on the interconnection board **600**. While there are many different layouts these boards can utilize such as parallel planes, clock tree distribution, etc., one of the more effective is a low cost single layer modular arrangement with many bonding locations **642**. As shown, a gate track **650** and source track **652** go across the length of the interconnection channels **654**. Source wire bonds are formed directly on the source track **652**. Each gate is bonded to individual gate pads **651** which are connected to the gate track through resistors **640**. The values of the resistors **640** are device and application dependent and will vary between module **100** configurations.

Power Substrate

FIG. 13 shows the power substrate **300** which is a metal-ceramic-metal layered structure designed to handle very high currents and voltages with the arrows again showing the gate direction to be matched with the boards **600**. Metals may be copper or aluminum at varying thicknesses, while the ceramic materials are typically alumina, Al₂O₃, aluminum nitride, AlN, or silicon nitride, Si₃N₄. The metal layers **302** are etched into topology specific patterns **330**, **340**, **350** as illustrated in FIG. 13 for a half bridge substrate **330**, FIG. 14 for a common source substrate **340**, and FIG. 15 for a common drain substrate **350** showing the upper and lower die **500** positions for each configuration. Also note that each of these layouts may be split into a dual channel arrangement by etching a line down the center of the substrates **300**. They may also be split into individual substrates per channel if desired. This may be useful for more harsh environments as the smaller substrates will experience less stress.

Housing

The housing **800** is formed in an injection molding process with reinforced high temperature plastic. The housing **800** serves many functions in addition to being a protective barrier to the sensitive semiconductors **500**. This includes voltage blocking, mechanical support for the captive fasteners **900**, guides for the power contact bending process, entry zones for gel passivation, vents for the gel passivation process, and self-strengthening internal ribs **812**. Many of these features are depicted in FIG. 16 and FIG. 17. High aspect ratio trenches are placed around the periphery of the power contacts **400** to increase the surface distance between exposed metal contacts, increasing voltage blocking capability.

FIG. 16 shows the high temperature plastic housing topside features including the creepage extenders **802**, the passivation entries and vents **804**, the captive fasteners apertures **806**, the labeling area **808**, and the power contact pinch and radius **810**. FIG. 17 shows the backside features including the strengthening ribs **812**, the thick bolt hole core sections **814**, the bolt head clearance recess **816**, the bottoms of the fastener insets **818**, the power contact entryways **820**, and the wire bond clearance apertures **822**.

FIG. 18 shows how the housing **800** slides over the electronic sub assembly to form the top of the module **100**, with the power contacts **400** routed through the narrow openings **820**. The housing **800** is bolted **830** at two points to threaded holes **290** on the base plate **200**. At this stage the gel passivation material is injected into the module **100** and fully cured. Multiple openings and vents **804** assist this assembly step. The slices **820** in the housing **800** for the power contacts **400** have drafted "guides" to aid this process, and a rounded fillet **810** on top to aid in the bending procedure. These are illustrated in FIG. 19.

Configurability

As discussed earlier in this document, the power module **100** is configurable in a variety of useful power electronic topologies. These include half bridge, common source, and common drain. Splitting the channels, through layout changes in the power substrate **300** and gate & source kelvin board **600** and alterations to the power contacts **400** and housing **800**, allows three more configurations, including a full bridge, common source dual channel, and common drain dual channel.

FIG. 20 displays the first external configuration **150** for half bridge, single channel common source, and single channel common drain configurations. There are four locations **701**, **702**, **703**, **704** for the gate driver connections **700**, two on each side. Either or both sides may be used for this purpose. For the dual channel arrangement **152**, shown in FIG. 21, the power contacts **400** are split and provide two fully isolated channels. Gate drive connectors **700** on both sides are now required. This arrangement is used for a full bridge, dual channel common source, and dual channel common drain topologies.

For higher currents and for customers who desire a single module, a larger side-by-side arrangement of a dual power module **200** may be fabricated from two modules built side by side into a single housing **800**. This is illustrated in FIG. 22.

Reference numerals used throughout the detailed description and the drawings correspond to the following elements:

- power module **100**
- power loop **110**
- shared current paths **120**
- first external configuration **150**
- dual channel arrangement **152**
- base plate **200**
- mounting holes **203**
- standoffs **210**
- threaded holes **212**
- threaded holes **290**
- power substrate **300**
- metal layers **302**
- first topology pattern half bridge substrate **330**
- second topology pattern common source substrate **340**
- third topology pattern common drain substrate **350**
- power contacts **400**
- first power contact **410**
- second power contact **420**
- third power contact **430**
- base **450**
- bonding surface **452**
- solder catches **454**
- vertical body **460**
- first bend **462**
- leading edge **464**
- opposite surface **466**
- contact top **470**
- second bend **472**
- upper position **480**
- lower position **490**
- power devices **500**
- first paralleled power device **501**
- second paralleled power device **502**
- third paralleled power device **503**
- fourth paralleled power device **504**
- fifth paralleled power device **505**
- sixth paralleled power device **506**
- seventh paralleled power device **507**
- eight paralleled power device **508**
- ninth paralleled power device **509**

tenth paralleled power device **510**
 eleventh paralleled power device **511**
 gate & source kelvin interconnection board **600**
 first interconnection channel **602**
 external die aperture **603**
 second interconnection channel **604**
 internal die aperture **605**
 first interconnection position **611**
 second interconnection position **612**
 third interconnection position **613**
 fourth interconnection position **614**
 individual ballast resistors **640**
 bonding locations **642**
 gate track **650**
 gate pads **651**
 source track **652**
 interconnection channels **654**
 gate drive connectors **700**
 first gate driver connection location **701**
 second gate driver connection location **702**
 third gate driver connection location **703**
 fourth gate driver connection location **704**
 housing **800**
 creepage extenders **802**
 passivation entries and vents **804**
 captive fasteners apertures **806**
 labeling area **808**
 power contact pinch and radius **810**
 strengthening ribs **812**
 bolt hole core sections **814**
 bolt head clearance recess **816**
 fastener insets **818**
 power contact entryway slices **820**
 wire bond clearance apertures **822**
 bolt **830**
 fasteners **900**

From the foregoing, it will be seen that this invention well adapted to obtain all the ends and objects herein set forth, together with other advantages which are inherent to the structure. It will also be understood that certain features and subcombinations are of utility and may be employed without reference to other features and subcombinations. This is contemplated by and is within the scope of the claims. Many possible embodiments may be made of the invention without departing from the scope thereof. Therefore, it is to be understood that all matter herein set forth or shown in the accompanying drawings is to be interpreted as illustrative and not in a limiting sense.

When interpreting the claims of this application, method claims may be recognized by the explicit use of the word 'method' in the preamble of the claims and the use of the 'ing' tense of the active word. Method claims should not be interpreted to have particular steps in a particular order unless the claim element specifically refers to a previous element, a previous action, or the result of a previous action. Apparatus claims may be recognized by the use of the word 'apparatus' in the preamble of the claim and should not be interpreted to have 'means plus function language' unless the word 'means' is specifically used in the claim element. The words 'defining,' 'having,' or 'including' should be interpreted as open ended claim language that allows additional elements or structures. Finally, where the claims recite "a" or "a first" element of the equivalent thereof, such claims should be understood to include incorporation of one or more such elements, neither requiring nor excluding two or more such elements.

What is claimed is:

1. A power module apparatus, comprising:

a base plate defining a topology pattern;
 a power substrate positioned above the base plate;
 at least two power contacts, each of the at least two power contacts electrically connected to the power substrate;
 at least two parallel shared current path power devices electrically connected to the at least two power contacts;
 a gate and source board mounted above the power substrate, the gate and source board including a first interconnection channel and a second interconnection channel, each interconnection channel mounted in an interconnection position selected from a position group, the position group consisting of a first interconnection position, a second interconnection position, a third interconnection position, and a fourth interconnection position;
 gate drive connectors electrically connected to the gate and source board;
 a housing secured to the power substrate, the gate drive connectors and the at least two power contacts extending through the housing, the housing defining fastener apertures;
 fasteners positioned in the fastener apertures; and
 the at least two power contacts bent over the fastener apertures to retain the fasteners in the fastener apertures.

2. The apparatus of claim 1,

wherein the topology pattern forms a half bridge substrate.

3. The apparatus of claim 2, wherein:

the first interconnection channel is mounted in the first interconnection position; and

the second interconnection channel is mounted in the third interconnection position.

4. The apparatus of claim 2, wherein:

the first interconnection channel is mounted in the second interconnection position; and

the second interconnection channel is mounted in the third interconnection position.

5. The apparatus of claim 1,

wherein the topology pattern forms a common source substrate.

6. The apparatus of claim 5, wherein:

the first interconnection channel is mounted in the first interconnection position; and

the second interconnection channel is mounted in the fourth interconnection position.

7. The apparatus of claim 1,

wherein the topology pattern forms a common drain substrate.

8. The apparatus of claim 1,

wherein the at least two parallel shared current path power devices include a first paralleled power device, a second paralleled power device, and a third paralleled power device.

9. The apparatus of claim 8,

wherein the at least two parallel shared current path power devices include a fourth paralleled power device.

10. The apparatus of claim 9,

wherein the at least two parallel shared current path power devices include a fifth paralleled power device, and a sixth paralleled power device.

11. The apparatus of claim 10,

wherein the at least two parallel shared current path power devices include a seventh paralleled power device, and an eighth paralleled power device.

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12. The apparatus of claim 11,
wherein the at least two parallel shared current path power
devices include a ninth paralleled power device, and a
tenth paralleled power device.
13. The apparatus of claim 12, 5
wherein the at least two parallel shared current path power
devices include an eleventh paralleled power device.
14. The apparatus of claim 1,
wherein the housing defines passivation entries and vents.
15. The apparatus of claim 1, 10
wherein the housing defines a power contact pinch and
radius for receiving and bending one of the at least two
power contacts.
16. A gate and source board apparatus for use with multiple
power die positioned in parallel, the apparatus comprising: 15
a track paralleling the multiple power die;
at least two gate bond pads positioned parallel to the track;
and
individual ballast resistors selectively connecting each of
the at least two gate bond pads to the track. 20
17. The apparatus of claim 16,
wherein the track is a gate track.
18. The apparatus of claim 17,
wherein the track is a source track.

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